Study of Space Cabin Atmospheres

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Status Report For the Period

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I. Summary of Activities

The major effort during this work period involved extending the initial survey of the piezo-electric, acoustical, and hot wire particle sensors described in our last status report.

Our purpose was to make preliminary comparison of these techniques to determine which of the three sensors appeared to be best suited for automatic monitoring of aerosols in the $1\,\mu$ to $30\,\mu$ size range.

A. Piezo-Electric Particle Sensor

A method commonly employed for the detection and size measurement of micrometeoroids utilizes a piezo-electric crystal sensing element. The hypervelocity impact of the particle on the crystal element generates a voltage transient whose magnitude is a function of the momentum transferred to the crystal. Although the precise mechanism involved in this transformation is not fully understood, the detector is certainly useful in detecting particle numbers (or impacts) and with laboratory calibration it has been possible to relate the resulting pulse sizes to micrometeoroid diameters[1]

Utilization of particle momentum for size measurement has also been attempted in an apparatus described by Katz[2]. Since this unit was to be used for measurement of raindrop size, the particle sizes to be observed were necessarily quite large. According to Mason[3], however, certain operational problems have been noted with this instrument.

In evaluating the application of the piezo-electric crystal detector to the measurement of particle size distributions for particle sizes below 30 microns, it is necessary to consider first the momentum threshold of available sensors which then permits calculation of the minimum particle sensitivity.

The transfer of momentum of an incoming particle (P_i) to a target (P_x) can be described by the expression:

$$P_x = K_p P_i \qquad \text{....(1)}$$

where K_p is the momentum transfer parameter of proportionality. (If the collision is inelastic, K_p is equal to one; for perfectly elastic collisions, K_p equals two).

The momentum of a particle can be given as the product of its mass times its velocity, i.e.

$$P_i = mv \qquad \text{....(2)}$$

so that $P_x = K_p\, mv$ ....(3)

With spherical particles of density, ρ

$$P_x = K_p \left(\frac{\pi d^3}{6}\right) \rho\, V \qquad \text{....(4)}$$

Expression (4) indicates that for a given particle velocity the momentum delivered to the crystal detector varies as the cube of the particle diameter. The resolution of particle sizes should, therefore, be fairly sharp.

The momentum threshold or sensitivity of a typical microphone detector, e.g. for the Explorer I satellite, is in the order of 10^{-3} dyne-sec[4]. According to Rogallo and Neuman[1] it is possible to extend this sensitivity to about 10^{-5} dyne-sec. This level appears to be an ultimate sensitivity since at this point any external vibration will result in a background signal from the detector unit. At low particle momenta, the impacting signal is completely lost due to the unfavorable signal to noise ratio.

Writing equation (4) as

$$d = \left(\frac{6}{\pi} \frac{P_x}{K_p \rho v} \right)^{1/3} \qquad \ldots.(5)$$

yields an expression for the particle diameter as a function of the other parameters.

At fairly high velocities, it is necessary to assume that most particles will adhere to a surface upon impact. Thus a value of one must be used for K_p, the momentum transfer parameter. Using this value and the minimum value for P_x of 10^{-5} dyne-sec given by Rogallo and Neuman[1], the detectable particle size becomes:

$$d = 267(v\ \rho)^{-1/3} \qquad \ldots.(6)$$

Table I lists the minimum size of a unit density particle detectable for various impact velocities calculated from equation (6).

As can be seen from Table I, velocities of about 1000 cm/sec (1960 ft/min) would allow particle resolution down to about 25 microns. To detect a 10μ particle, a velocity of an order of magnitude greater would be required. Increasing the impaction velocity increases the size range of particles which would stick to the target. Since the momentum transferred from particle to target is a function of target weight, a calibration drift resulting from particle collection on the crystal would be expected. Since some of these particles could not be measured by the detector, it would be impossible to compensate for this drift.

Therefore, based on our analysis we considered that a piezo-electric crystal detector with a sensitivity of approximately 10^{-5} dyne-sec would not be useful for measurement of particles below 30 microns. Because the value of 10^{-5} dyne-sec seems to represent the best

TABLE I

MINIMUM PARTICLE SIZE DETECTABLE WITH PIEZO-ELECTRIC CRYSTAL SYSTEM OF 10^{-5} DYNE-SEC SENSITIVITY

(Unit Density Particles)

IMPACT VELOCITY (cm/sec)	MINIMUM SIZE DETECTABLE, MICRONS
10^0	267
10^1	124
10^2	57.2
10^3	26.7
10^4	12.4
10^5	5.7

(1 cm/sec = 1.96 ft/min)

minimum sensitivity attainable, further work on this type of device for respirable particle detection in a space cabin atmosphere does not seem fruitful at the present time.

B. Acoustical Particle Counter

A design described by Langer[5] was used in our investigation of acoustical particle detectors. Langer had applied this unit in counting the concentration of ice crystal particles with a resolution of 5μ. Although no functional relationship between signal size and particle diameter over a particle size range from 5 to 500μ was demonstrated, Langer did suggest size discrimination could be achieved by proper acoustic design of his sensor.

Figure 1a shows the design characteristics of the particle counting element and Figure 1b a schematic diagram of the experimental apparatus we used to evaluate this device. Particles carried through the detector were retained on a filter downstream of the sensing element. The acoustical signal that was generated when a particle passed through the sensing element was detected with a General Radio Type 1560-P40 ceramic microphone. The microphone output signal was amplified by a General Radio 1560-P4 preamplifier and applied to the input of a General Radio 1558A Octave Band Analyzer. The bank pass filter on the Octave Band Analyzer was used to pass selected signals in the 2400-4800 Hz range for display on an oscilliscope. The purpose of the band pass analyzer, which was not used by Langer, was to reduce incidental noise reaching the scope. For example, we found that the unit would not only respond to particles but also to background laboratory noise.

In our initial tests, Orchard grass pollen (Dactylis glomerata) (31μ), was used as the test aerosol. Each particle passing through the detector triggered a pulse on the oscilliscope and a typical pulse with a height exceeding 2 volts was generated. Each pulse consisted of two major oxcillations followed by a ringing which was gradually damped out. The period of these oscillations was about 0.3 millisecond. Total residence time of the particle in the capillary section of this detector at a flow of 6 lpm was about 1 millisecond. These values and the pulses produced were similar to those described by Langer[(5)].

In order to effect a calibration of the detector, it was necessary to utilize some system for rapid counting of the produced pulses. To accomplish this, the output from the analyzer was inserted directly into a Baird Atomic 131A Glow Tube Scaler. To determine optimum voltage discriminator level, a series of runs were made at various discriminator settings. Figure 2 shows a plot of counting level as a function of discriminator settings.

This curve indicates that there is no sharp discrimination cut-off level for the first two pulses. From the pulse pattern one would expect a sharp cut-off at about 2 volts. Therefore, it was tentatively concluded that the height of these initial pulses varies, even for particles of the same size.

To investigate this possibility, a series of runs were made in which, by carefully collecting it after each pass, the same particle was passed through the detector several times. To facilitate this collection, glass and plastic spheres of 500, 600, and 700 micron diameter were used to discretely actuate the sensor. Sample data for a 700μ glass bead passing through the sensing element is shown in Table II.

These data indicate that the signal amplitude of the initial pulses may vary by more than 100% for a single particle, a problem which presents a major impediment to the use of this system for particle sizing. It is interesting to note that there was no change in the frequency of this signal when single particles in the size range 100 to 700 microns were passed through the detector thus ruling out frequency shifts as a method of particle size analysis. We believe the differences in amplitude which we

TABLE II

VARIATION IN PULSE AMPLITUDE FOR A

SINGLE 700μ DIAMETER PARTICLE

RUN NO.	PULSE AMPLITUDE, VOLTS
1	0.91
2	1.19
3	0.63
4	1.19
5	0.79
6	0.63

observed for the same particle are due to flow changes introduced by variations in the particle's path of travel through the sensor.

Although our brief review indicates many major problems in the application of these techniques to routine aerosol counting, we believe further work is justified. In our opinion, the next development step for this detector should be extensive theoretical work to explain precisely the phenomena which are observed. In this manner insight into techniques for optimization of design may become more apparent. Since the signal produced from this technique is audible, a relatively simple method is available for a direct reading particle counter. High gain amplification of the signal would not be required. There also exists a possibility for sophisticated treatment of the signal as a method for determining particle size.

C. Heated Wire Anemometer Particle Detector

The final method chosen for preliminary investigation was the hot wire anemometer method most recently described by Goldschmidt[6]. With this technique, which utilizes a constant temperature (300°C) hot wire anemometer probe (7), particles impacting on the probe produce a current pertubation which is demonstrated as a voltage pulse.

The size of this pulse depends on the physical state of the particle (solid or liquid) as well as on its size.

In the case of a liquid aerosol, evaporation of a droplet impacted on the wire causes a cooling of the wire. To maintain a constant wire temperature, additional heating current must be applied. Goldschmidt has shown that there is a linear relationship between heating current (voltage pulse height) and droplet diameter and presents a discussion of the theory of operation of the sensor for droplets. Goldschmidt has also suggested the use of this apparatus for counting and sizing solid aerosol particles. With solid particles the voltage fluctuations are due to cooling from wire vibration after the impact.

Our interest in this device was due to its ability to discriminate between solid and liquid particles. One application of this sensor would be the evaluation of the drying of droplets generated by atomization of a solution.

To investigate the operation and possible applications of this device, a DISA 55D05 constant temperature anemometer having a 5μ filament sensor (Type 55A22) was used. The output of the anemometer was shaped and amplified in a RIDL 30-21 Biased Amplifier and then fed to both a TMC 101 Gammascope and a Bair[d] Atomic 131A Glow Tube Scaler. A test liquid aerosol (either water or ethylene glycol) was produced with a Pen-I-Sol nebulizer which according to Mercer, et.al., (8) produces an aqueous aerosol having a mass median diameter of 2.9μ.

Figure 3 shows a cumulative distribution curve for three runs using a water aerosol collected at a sampling velocity of 30 cm/sec (R_e = 332). The lower numbered channels represent lower voltages collected and hence smaller particle sizes. Although we have not calibrated the multi-channel analyzer, this curve demonstrates fairly good reproducibility in the individual channels. When the percent of pulses collected in each channel is plotted as a function of channel number, one obtains the type of distribution curve shown in Figure 4 for an ethylene glycol aerosol. The solid line curve represents the measured size distribution at a velocity of 44.5 cm/sec (R_e = 380) while the dotted line represents collection at a velocity of 359 cm/sec (R_e = 3080). It can be seen that when velocity is increased, the distribution curve is displaced toward the lower sizes. This refelcts an increased impaction efficiency with increased velocity for these smaller sizes. In both cases the background count of the detector was negligible, amounting to only a few percent of the total count. The distribution curve shift was also noted when water was the aerosol.

We have also attempted to apply this sensor to solid particles as suggested by Goldschmidt, but to date we have not been able to actuate the sensor in this mode.

II. Future Activities

1. Of the three particle sensors studied during this period, the hot wire anemometer appears to offer the most promise for further development, particularly because of its ability to discriminate between solid and liquid aerosols. If used in connection with a light scattering device it could give the relative proportions of liquid and dry aerosols in an atmosphere. In addition to a detailed study of the accuracy of the device as a counter, and its ability to discriminate particle size, there are a number of possible operational limitations which must be investigated. Probably the most significant of these is the modified performance of the wire element due to the residence of solid particles on the wire, residual material resulting from droplet evaporation, and deposits from thermally degradable materials.

The performance of this sensor will be studied in greater detail during the next grant period in an attempt to develop an operable sensor suitable for space cabin atmospheres.

2. Additional attention will be given the utilization of the multi-channel analyzer for the display of data generated by particle sensors.

3. Methods of handling the particulate sampled by the membrane tape system on the Aerosol Particle Analyzer to permit particle identification and count correlation with the light scatter sensor will be investigated.

FIGURE 1A

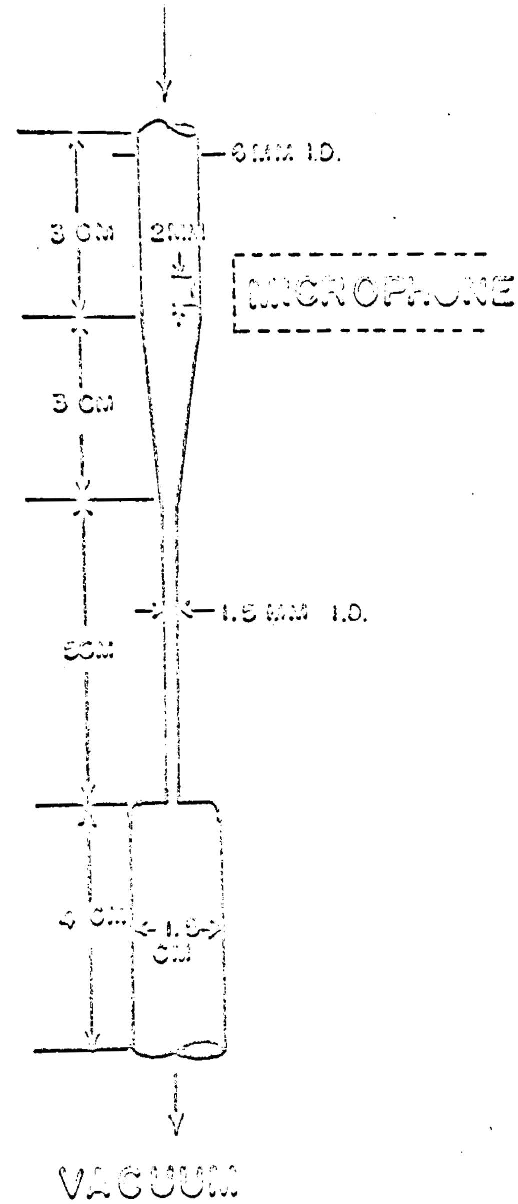
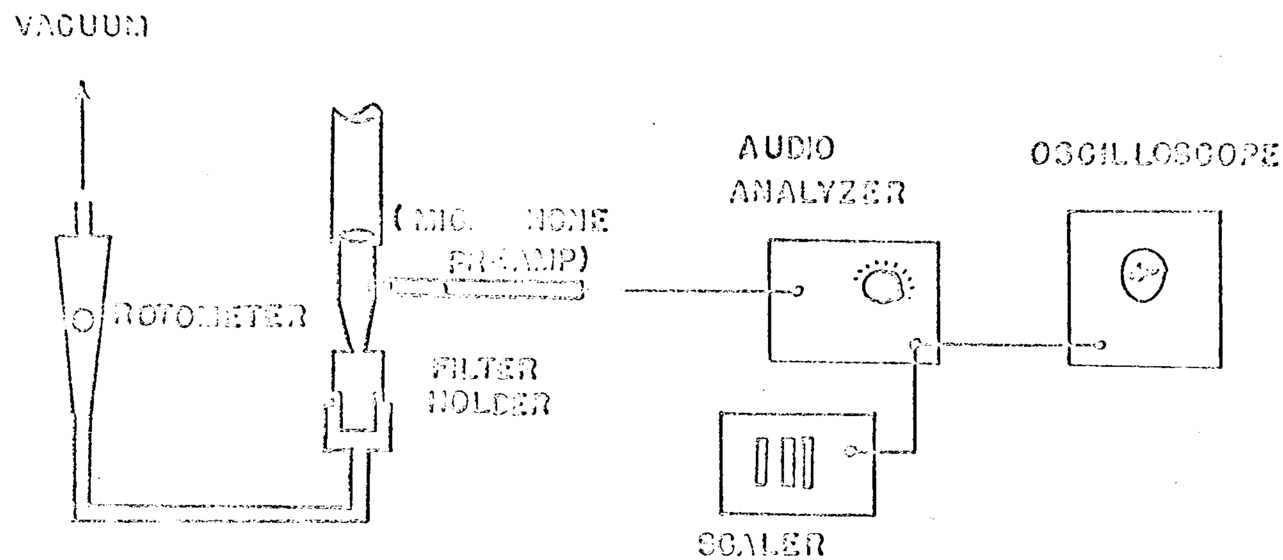


FIGURE 13


VACUUM
ROTOMETER
(MIC. HONE
PREAMP)
FILTER
HOLDER
AUDIO
ANALYZER
OSCILLOSCOPE
SCALER

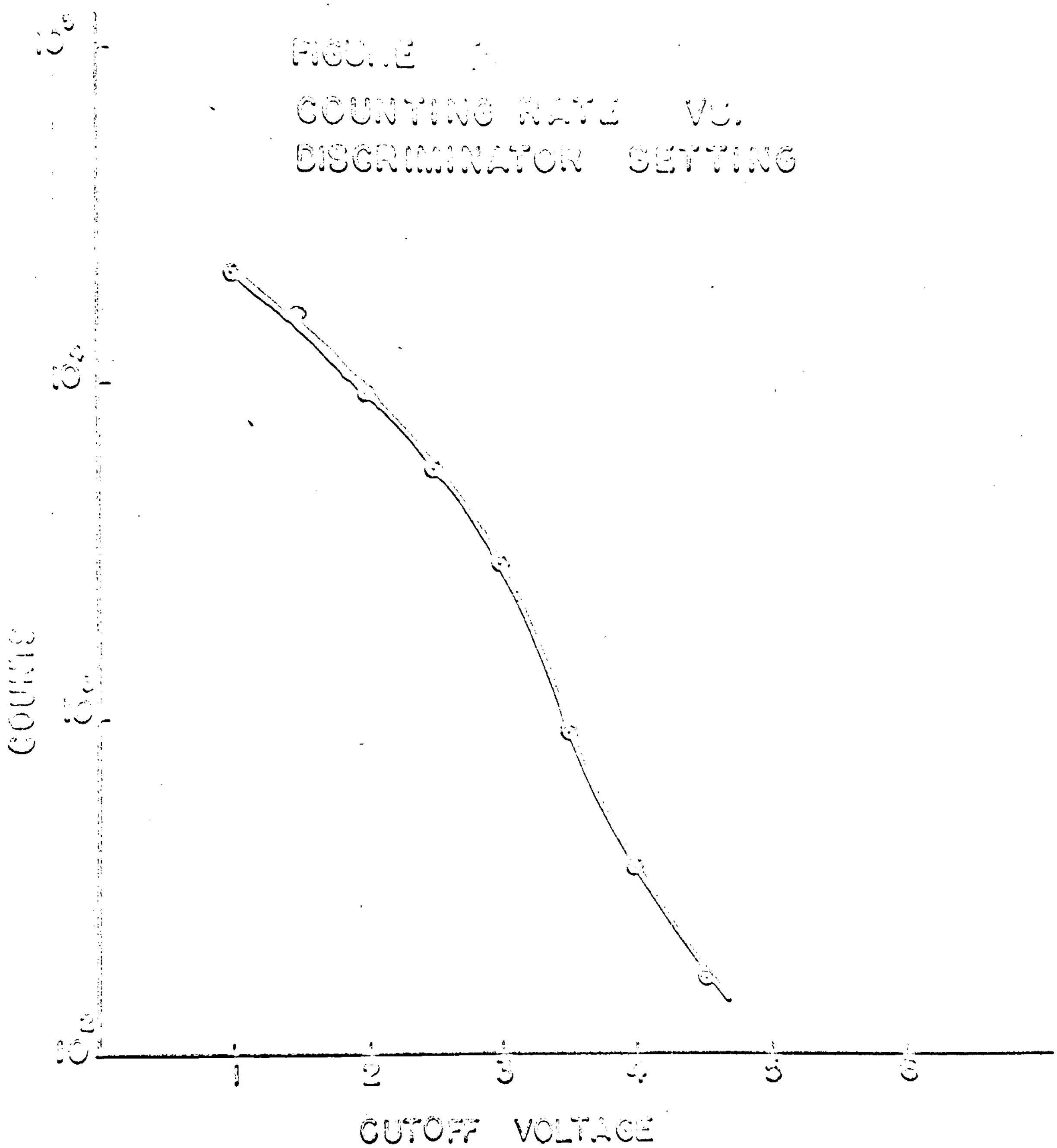


FIGURE 1
COUNTING RATE VS.
DISCRIMINATOR SETTING
COUNTS
1
2
3
4
5
6
CUTOFF VOLTAGE

FIGURE 3

CUMULATIVE (%) VS. CHANNEL

H_2O AEROSOL

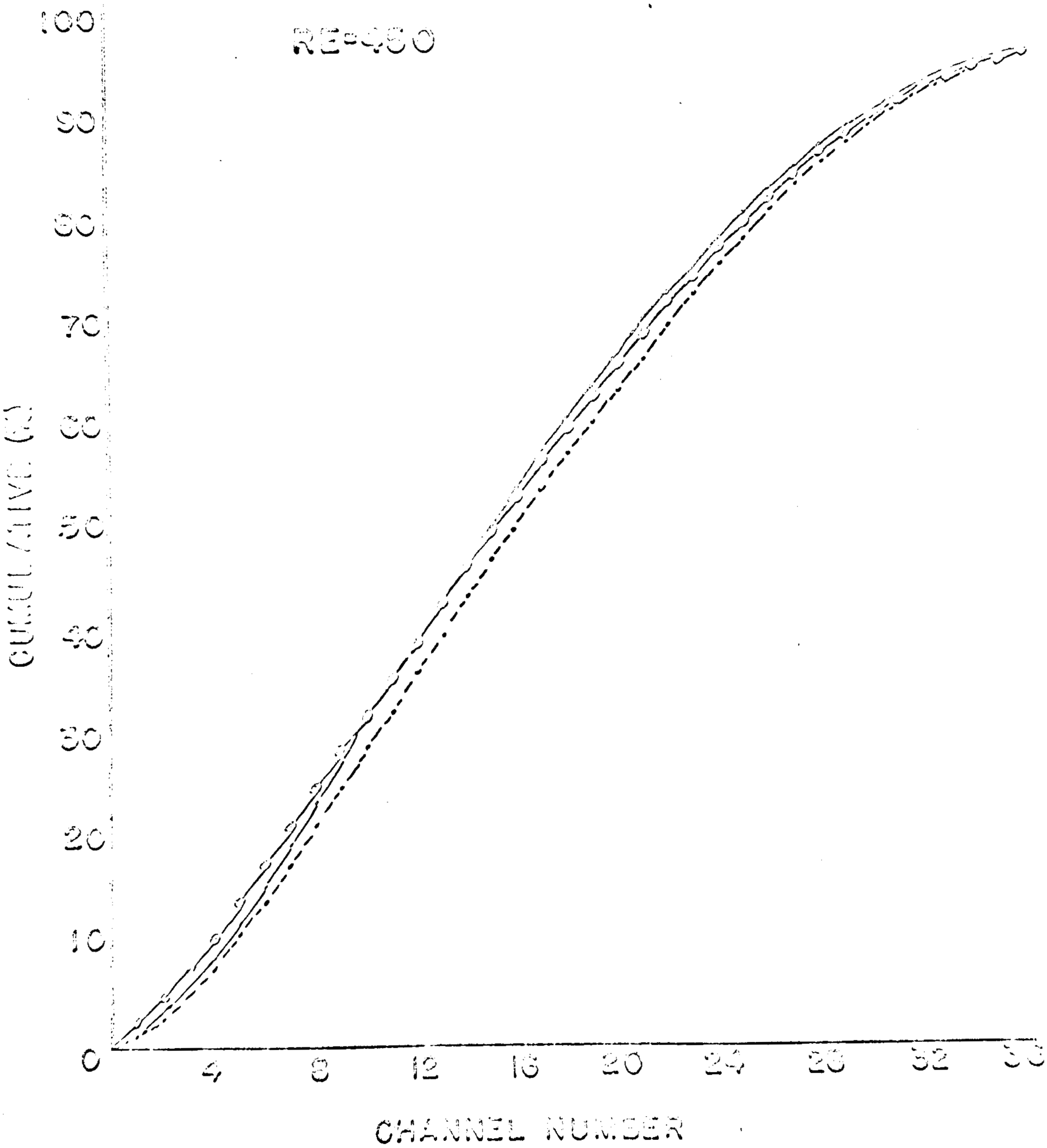
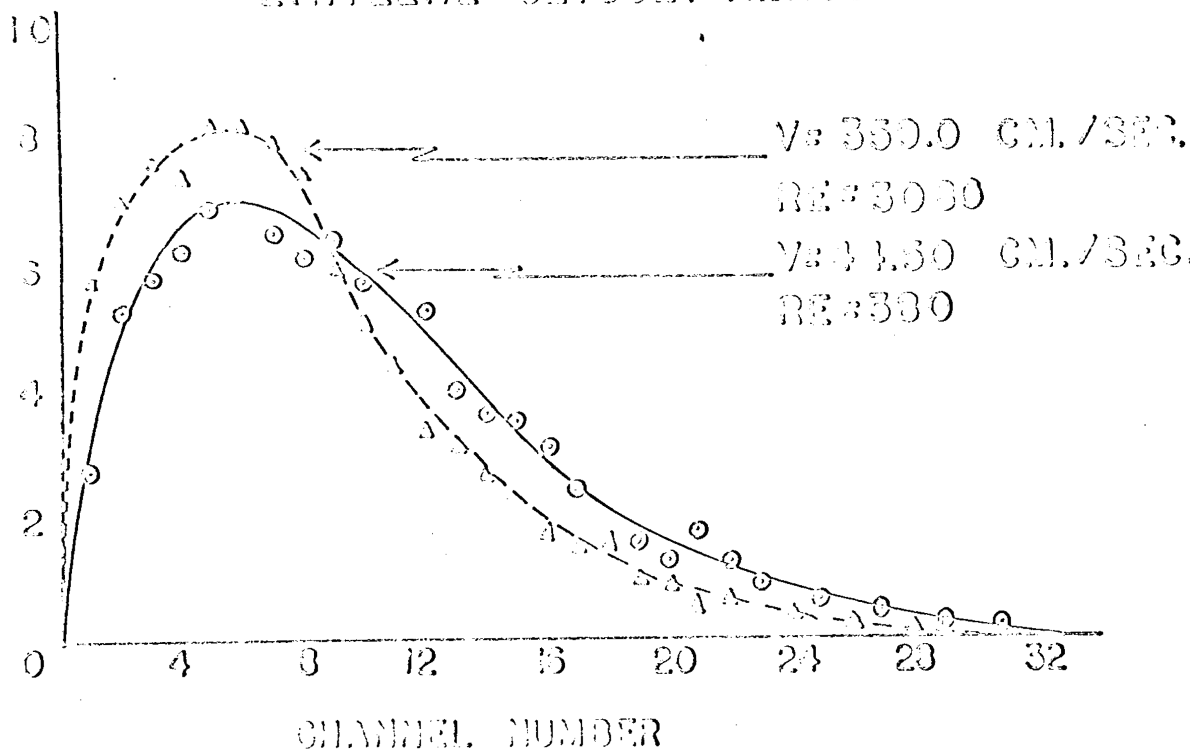


FIGURE 4

INDICATED SIZE DISTRIBUTION

PENN. SOL. NEB.

ETHYLENE GLYCOL, AEROSOL



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